TECHNICAL TRANSLATION

F-51

EXPERIMENTAL ELECTRONIC EQUIPMENT FOR MEDICAL TELEMETRY

By T. Matsuo

Translation of Material No. TM-51001,
Mitsubishi Electric and Mfg. Co., Tokyo Bldg.,
Marunouchi, Chiyoda-Ku (Tokyo), Nov. 20, 1959.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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1. Purpose

This project was initiated at the request of Professor Kentaro Takagi of the No. 1 Physiology Room of the Medical Department, Nagoya University. Its purpose is to devise a means of observing the action of the human body at a distance by observing the small electrical voltages of the electrocardiogram, electroencephalogram, Galvanic skin response, electromyogram, breathing, body temperature and environ-
F 5 1 ment (temperature,. altitude, activity, etc.) with a radio telemetry system. Such a system would allow the study of the human body or animals in action, to investigate the unknown cause of accidents under special conditions, to study the adaptability of a human body, analyze the phenomenon of exhaustion, and discover the most suitable ways of maintaining health under variable conditions.

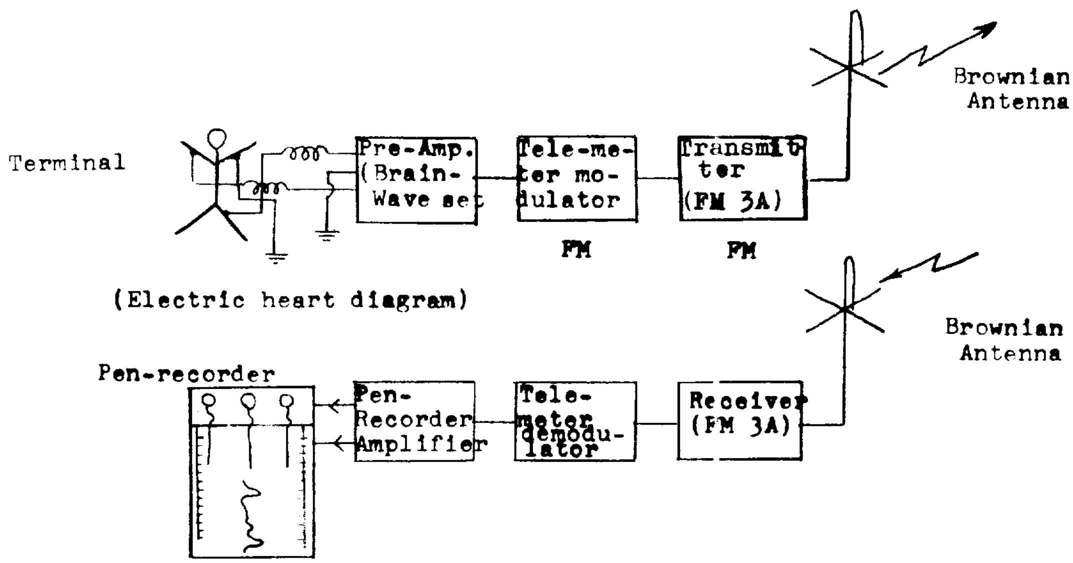
On September 7, 1959 we were asked to test the feasibility of the radio telemetry of a small bio-electric signal. Arrangements were made to telemeter a single electrocardiogram by setting up a radio link of approximately 5 km between the No. 1 Physiology room of Nagoya University and the Laboratory for the Study of Environment, Nagoya University. This was the basic experiment and was conducted in the middle of November. For radio transmitters we used the FM3A radio telephone set using call letters JS4WD and JS4WE for which we had a license. As for the telemetry equipment itself we ignored its volume, size, and weight and limited it to a single subcarrier. For the transmitter pre-amplifier and the receiver pen-recording amplifiers, we used the ones on hand at Nagoya University.

The frequency components of the electro-cardiogram pulse are said to be in the range 0.5 to approximately 200 lps. However, the recording pen limited the frequency response from 0.5 to approximately 60 cps with 10% linearity and this was adequate for our purpose.

When the electrocardiogram voltage is picked up from the body the peak voltage is less than one millivolt, and the peak voltage from electroencephalographic electrodes is in the neighborhood of ten micro-volts. Using these small voltages, special care must be taken with noise and interference and especially to eliminate commercial alternating current pickup.

2. The Telemeter System

The following is a block diagram of telemeter sy3tem constructed.



An FM-FM system of telemetering offers the followin; advantages:

1. Slight reduction in signal quality with noise.

2. In the small transmitter FM is easier to accomplish than other forms of signal modulation and requires small power consumption.

3. If an FM subcarrier is used, cross talk and noise can be reduced with the wider bandwidth and linearity requirements are simpler and it is easily adapted to conventional transducers used to obtain signals from the human body.

4. The total system is less complex than a time-division modulation system, thus there are advantages in small size and weight and in a reduced power consumption. These features make it attractive for future uses in sports, aviation, and space medicine.
5. Each channel is independent, easy to maintain, and is simple, which provides reliability.
6. As opposed to PPM or AM it can be recorded easily on a magnetic tape recorder in the form of a multiplex signal and subsequently can be corrected for known defects in the receving system. Such a recording preserves the information and can be duplicated.
7. There is considerable background in the FM-FM method of telemetry developed for other purposes.

For these reasons we decided to employ the FM-FM system and since Mitsubishi Electric had a permit to operate in the 150mc band the main transmitter was assembled without difficulty.

The following is a detailed explanation of the telemetry system:

At the transmitting station:

1. Attach an electrode to the human body to provide a bio-electric signal.
2. Amplify the transducer signal.
3. Modulate the frequency of the subcarrier oscillator with the amplified signal from the transducer.
4. The subcarrier oscillator output is used to frequency modulate the main carrier.
5. The transmitter is coupled to an antenna to radiate a signal.

At the receiving point:

1. The transmitted signal is received by the receiver antenna.

2. The receiver frequency-demodulates the carrier wave producing the subcarrier.
3. The subcarrier is frequency-demodulated to produce the original signal input waveform.
4. The demodulated signal (3) is amplified in the pen recorder apparatus and the pen makes a permanent tape record.

3. Characteristics of the transmitter

For radio link transmitters we decided to use the Mitsubishi Electric VHF/FM type, and the FM3A type of the Wireless Telephone Apparatus Transfer Department. This was due in part to the limited time available and the difficulties in obtaining additional permits. The important characteristics of these transmitters are as follows:

(a) frequency 151.89mc.

(b) power 25W(JS4WE), 50W(JS4WD)

(c) modulator crystal control phase-modulation

(d) frequency multiplication (2x3x2x2) = 24

(e) stability $\pm$ 0.002% (-20° C to 50° C)

(f) deviation maximum below IKc, 12rad/sec at 100% modulation

(g) frequency response relative to 1 Kc.,

0.3Kc less than - 10.5db.

2.0Kc less than $\pm 4 \pm 2$db.

3.0Kc less than $+6 \pm 2$db.

(h) linearity for DC input good linearity to 1 Kc at 70% modulation

(i) modulator input impedance 40 ± 10(ohms) 0.3 to 3Kc.

(j) input level at 1 Kc, 70% modulation at -4 ± 2 dbm.

(k) harmonic radiation

below - 80db at the carrier frequency

below - 60db outside the carrier bandwidth

(l) input circuit 75 ohm unbalanced.

(m) noise level less than - 20db at 1 Kc at 70% modulation

(n) signal to noise less than - 45 db at 1 Kc at 100% modulation

(o) AM component less than 5% at 100% modulation at 1 Kc

F 5 1 (p) power consumption

a. 500 VDC @ 200ma. (output 25W)

b. 250 VDC @ 70 ma.

c. 6.3V @ 6.3A

12.6V @ 3.2A

25.2V @ 1.7A

The characteristics of the receiver are:

a. double superheterodyne circuit

b. IF frequency (1) 5.25Mc, (2) 455 Kc

c. number of tubes 16

d. frequency stability +0.002% (-20° C + 50° C)

e. signal to voice with 100% modulation at 1Kc

0db. input (1 uv) S/N = 15db.

20db. input (10V.) S/N = 35db.

f. bandwidth at 6db points is ± 12Kc

g. selectivity 70db down at ± 25Kc

h. frequency response relative to 1Kc

at 0.3 Kc less than +6db ± 2db

at 2.0Kc less than -4db ± 2db

at 3.0Kc less than -8db ± 2db

i. the output variation at 1Kc 70% modulation, output 30dbm, is less than -20db with 600ohm termination.

j. squelch sensitivity: from 0 to 20db input, with control

k. Image rejection more than 80db.

l. Intermodulation distortion 40Kc and 80Kc = 65db. ($1\mu V = 0db.$)

m. Voltage sensitivity $\pm$ 40Kc at least 80db.

n. power consumption

  a. 250VDC @ 100ma.

  b. 6.3v. @ 5.25A F 5 1

  c. 12.6v. @ 2.7A

  d. 25.2v. @ 1.4A

The first experiment was conducted using JS4WD (50W) as the telemetering transmitter located at Tsurumahi Cho Showa District, Nagoya City, and JS4WE was used at the receiving location Furo Cho, Chitane District, Nagoya City. These two stations were used to make arrangements and to communicate between the two points. The ground-plane antenna was tied to a bamboo rod on the top of the Medical School building (the 4th floor) at the transmitting point. The receiving ground-plane antenna was tied to the ladder on the tower of the Engineering School (the 5th floor). The height of both antennas above ground was about 30 meters and the distance between them was about 4.5 Km.

The received power at the ground plane receiving antenna is given by:

$$\frac{W_2}{W_1} = \left(\frac{h_1' \cdot h_2'}{d^2}\right) \cdot g_1 \cdot g_2$$

where:

W_1 = radiated power (50W) from the transmitter antenna

W_2 = received power

h_1' = height of the transmitting antenna above ground (30m.)

h_2' = height of the receiving antenna above ground (30m.)

g_1 = transmitting antenna gain $(\cong 1)$

g_2 = receiving antenna gain $(\cong 1)$

d = distance between the two antennas (4500m.)

Using these values, the received power is calculated to be about 10^{-7} watt. The receiver input voltage can be calculated from:

$$W_2 = \left(\frac{E\ \lambda}{2\ \pi}\right) \cdot \frac{g_2}{120}$$

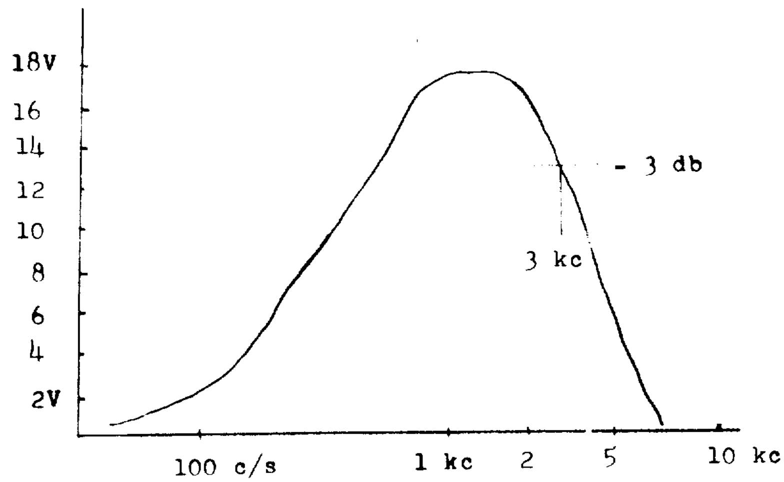
F 5 1 where W_2 = the received power (10^{-7}W.)

λ = wavelength (2m)

g_2 = the receiving antenna gain $(\cong 1)$

Using these values: $E = 1.1 \times 10^{-2}$ V/M. If $1\mu v/m = 0db$ then E is at a level of 80.5db. which is adequate to maintain a good signal to noise ratio.

Because of patent restrictions the telemeter modulator and demodulator had to be connected through the telephone handset. A step-down transformer was used at the receiver to feed the pen recorder (40 ohm input) and a DC marker signal was added. The result of the measurement of the radio circuit transfer function from the microphone terminals to the receiver output terminals is shown on the following diagram.



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4. Selection of the sub-carrier frequency.

Authoritative standards for sub-carrier frequencies are published by the American Inter-Range Instrumentation Group (IRIG).

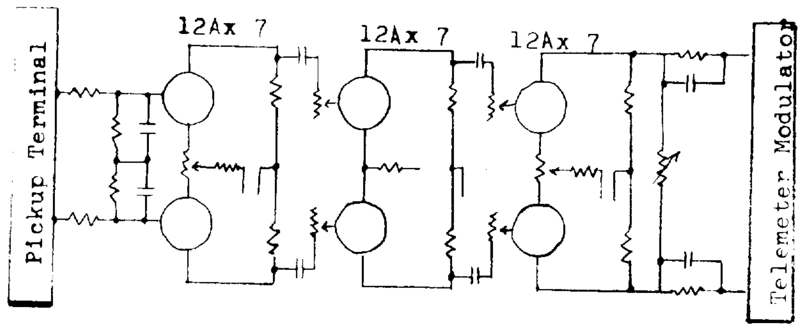
According to this group, 18 channels can be established in the band 400 cps. to 70,000 Kc. The highest subcarrier channels should be used to transmit the high frequency data, but in our case the frequency response 0.3 to 3 Kc. of the radio link limited the upper subcarrier channel frequency to 3Kc. Thus channel 8 (IRIG) was chosen, which has a center frequency of 3Kc and with 7.5% modulation (FM) the channel occupies the band 2775 Kc to 3225 Kc. If the modulation is restricted to 5%, the information bandwidth is 45cps. Since we wished to transmit up to 60cps we reduced the percentage modulation according to the relation:

$$\text{percent modulation} = \frac{\text{subcarrier center frequency}}{\text{signal frequency.}}$$

In order to monitor the subcarrier, it was amplified and powered a loudspeaker which allowed us to listen to the frequency change caused by the heart-beat signal. This was very convenient and it became known as the heart-monitor.

5. Outline of the pre-amplifier

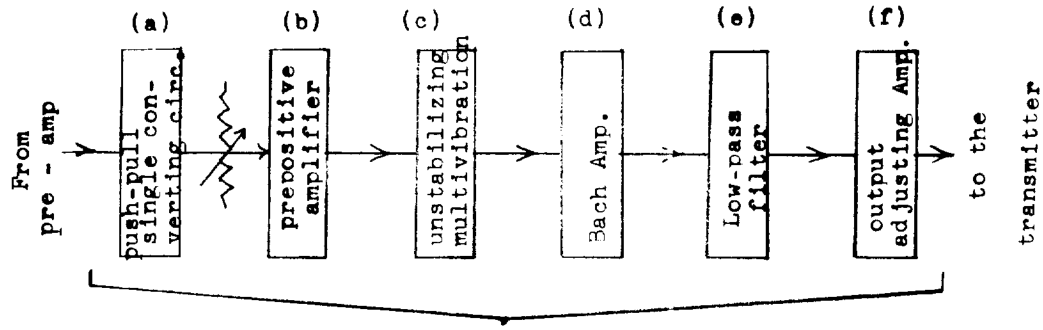
The model ME-7D Ko-Den Company electroenchephalograph amplifier was used for a pre-amplifier. The following figure shows a block diagram, and the electron tube filaments were powered by DC.



The telemeter modulator requires an input of about 0.075v. for 7.5% FM of the modulator. For the brain-wave signals this requires pre-amplification of about 60-70db. In the case of the heart wave with about 1mv input, the required amplification is a 35-40db. These inputs are small and are easily accompanied by pickup of electrical noise and interference from commercial power lines, since the impedance is relatively high. In order to reduce this effect, each stage of the pre-amp is operated in push-pull so that common pick-up is eliminated and the system is balanced to ground.

6. Telemeter modulation

The telemeter sub-carrier modulation is accomplished as follows and the block diagram shows the principal stages of the modulator.



a. Push-pull to single ended stage.

The input to the subcarrier is unbalanced to ground and the push-pull output signal of the preamplifier stage must be converted to a single ended terminal pair. This is accomplished with a phase-inverting stage and a passive adding network. Such a stage accomplishes the signal transformation and results in a noise and hum-free single ended output suitable for the amplification of the very small brain-wave potentials. The output of this stage is between 0. lv. and 1.0 volt.

b. Amplifier

This stage is a flat amplifier which is used to inject a controller voltage into the multivibrator to change its frequency. For this reason it must be designed to be stable so that the no-signal stability of the multivibrator will be high. The stage is as linear as the tube will permit and the gain is flat over the frequency range 0. 5cps to about 500cps.

c. Unstable (voltage-controlled) Multivibrator

A voltage-controlled unstable multivibrator is used as the sub-carrier oscillator One of the feedback paths is designed with a shorter time constant than the other in order to provide the greatest range of linearity about the center frequency. In this oscillator the linear deviation range is about $\pm$ 30% of the center frequency.

The center frequency is affected by the power supply voltages, but if these are regulated, the long-term stability of the center frequency is about 0.3% which is more than adequate for the purpose.

The relation between the input signal to the preceding stage grid and the oscillator frequency is shown in the following diagram.

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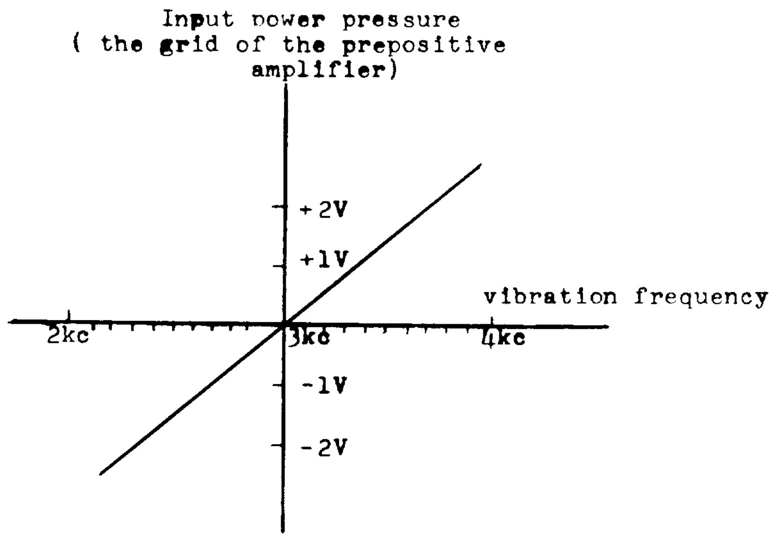


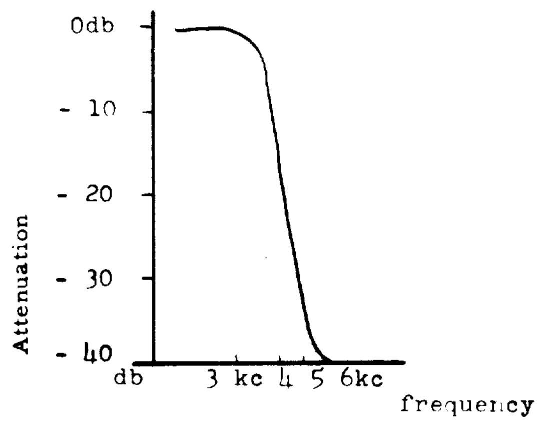
d. Buffer amplifier

A cathode-follower circuit is used following the multivibrator circuit in order to load the oscillator as little as possible and to secure a low impedance output to match the following low pass filter.

e. Low-pass filter

The waveshape produced by the multivibrator is rich in harmonic frequencies which can interfere with other subcarrier channels by producing cross-talk and noise voltages. In this single subcarrier system a simple low-pass filter is used to filter the subcarrier output rather than a bandpass filter. This low-pass filter provides up to 40db. attenuation for the second and third harmonics of the center frequency.

The frequency response of the filter is shown in the :ollowing diagram.



f. Output matching transformer

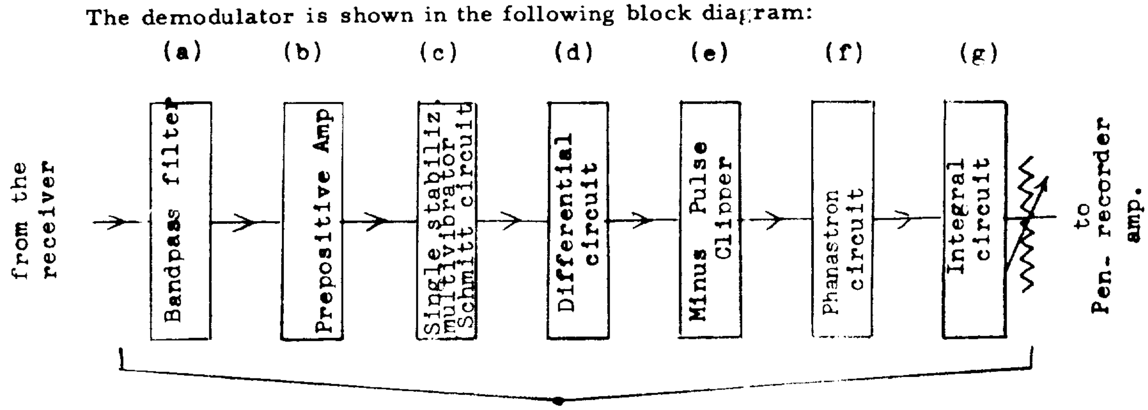
The transmitter is designed for a 40ohm carbon microphone input and an impedance matching the output of the low-pass filter to the transmitter is required. This is done with a transformer. A blocking capacitor is used on the transformer secondary so that a DC marking pulse can be inserted. The matching transformer provides -4dbm. for $\pm$ 3Kc (70% modulation).

The electron tubes used in the subcarrier modulator are:

2 - 12AU7, 2 - 12AT7 and it requires 40ma. at 150v DC (regulated) and 600 ma. at 12.6v DC.

7. The Telemeter Demodulator

The demodulator is shown in the following block diagram:

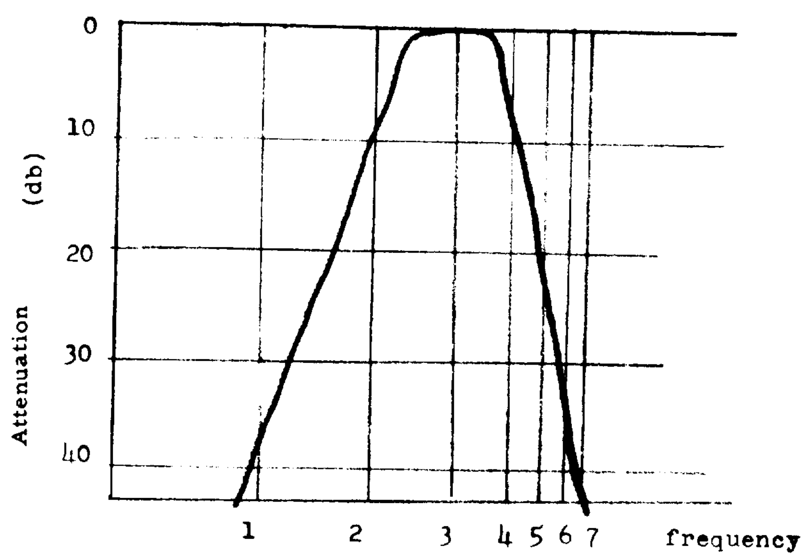


The demodulation is accomplished by integrating the output of a fixed height-fixed width pulse generator which is triggered by the cycles of the incoming signal. This type of demodulator is relatively insensitive to noise and is quite linear with good frequency response.

A brief explanation of the major circuit components is presented below.

a. Bandpass filter

F 5 1 In the case of multiple subcarriers this element separates the respective center frequencies. For the single subcarrier used in this experiment it is not required to employ a band-pass filter but it was included to take advantage of the noise reduction offered by the reduced bandwidth. The filter employed offers 20db attenuation 2Kc on either side of the center frequency. Thus, even if there is 60 cps induced noise in the transmitter it does not pass the filter. The frequency response of the filter is shown in the accompanying diagram:



b. The amplifier

This is a high-gain amplifier stage for the purpose of driving the Schmitt trigger circuit. This stage uses a 6CB6 tube.

c. One-shot multivibrator (Schmitt & Rigger)

This stage produces a rectangular wave form from a sine wave input signal. One rectangular pulse is produced for each cycle of the input frequency. The output pulse amplitude is largely independent of the input voltage level and this feature of the Schmitt circuit makes the system less susceptible to noise impulses.

d. The differentiator circuit

This circuit differentiates the leading and trailing edges of the rectangular waveform of the Schmitt circuit. The front edge produces a sharp positive spike and the trailing edge produces a negative going pulse. In order to achieve good differentiation a large amount of attenuation is introduced so the Schmitt output pulse should be large.

e. The Negative pulse clipper

The negative going pulse produced in the differentiation is of no use, so a clipping stage is introduced to remove it. This clipper is a semi-conductor diode (Mitsubishi MD-34).

f. The Phanastron Circuit

This circuit generates a fixed amplitude fixed width pulse when it is triggered with a sharp positive pulse from the differentiator. The circuit uses a 6AS6 tube and the output pulse is taken from the screen circuit. The number of pulses produced by the Phanastron circuit is exactly equal to the number of cycles generated by the subcarrier oscillator in the transmitter. A buffer following the Phanastron shapes the square wave output into nearly sinusoidal shape for the integrator circuit.

g. The integrator circuit

This circuit integrates the output pulses of the Phanastron circuit and produces a DC voltage which is the anolog of the subcarrier input voltage at the transmitter. When using a pen recorder the inertia of the mechanism is such that a simple RD integrator is sufficient to achieve the required integration.

This completes the description of the demodulation apparatus. The demodulator input is from 1 to 30v rms and the output from the integrator is greater than 5v. for 10% subcarrier modulation. This is more than adequate to operate the pen recorder.

The demodulator uses 3-12AU7, 1-6CB6 and 1-6AS6 type electron tubes. The power supply voltages required are 6.3V. AC @ 1.5A., 255V. (regulated) @ 30ma,
F 5 1 a second 255V. (regulated) @ 30ma. and a bias supply of -150V DC (regulated) @ 25ma.

8. <u>The pen-recorder</u>

The pen-recorder used was one already at Nagoya Univeristy. The output of the demodulator had to be reduced to keep from overloading the pen. The pen amplifier is a push-pull circuit using a 6SL7 6SL7 and p-p 6V6's.

There was a difference in the pen-recorders used at the transmitter monitor and the receiving location. They did not record identical waveshapes for the same inputs. This is a factor which must be considered in system design. In this experiment, time did not permit the close examination of both pen characteristics.

9. <u>Power Supplies</u>

The AC power was supplied from commercial sources with a stabilizing transformer. The DC power was supplied with transformer-rectifier packs using 5U4 rectifiers and VR 150 and VR105 glow-discharge voltage regulator tubes. DC filament power was obtained from an oxide rectifier and the bias supply used a 6x4 rectifier with a VR150 .

Conclusions:

This experiment was very successful in telemetering the electrocardiogram as well as the E. K. G. brain-waves. The telemeter curves of the monitor and receiver locations compared very favorably.

The apparatus employed was assembled largely from parts already available and no attempt was made to miniaturize the equipment. It is possible, through transistorizing, to reduce the size considerably. It is necessary to design a more F
suitable electrode attachment to use such a system in sports, aviation or space 5 1
medicine. As such miniaturizing is achieved, the application of such apparatus will grow.

A large receiving apparatus can be installed in a central location and the small transmitter carried to the patient and diagnosis at a distance is possible.

From a practical point of view at least four channels should be available to transmit several signals simultaneously. It is not a difficult problem technically to provide the additional channels.

Translated by Research International Associates,
Division of John F. Holman and Co., Inc.,
5034 Wisconsin Avenue, N.W., Washington 16, D.C.

Engineering School
Nagoya University
(Receiving Side)

Institute of Cosmic Rays
(Dome)

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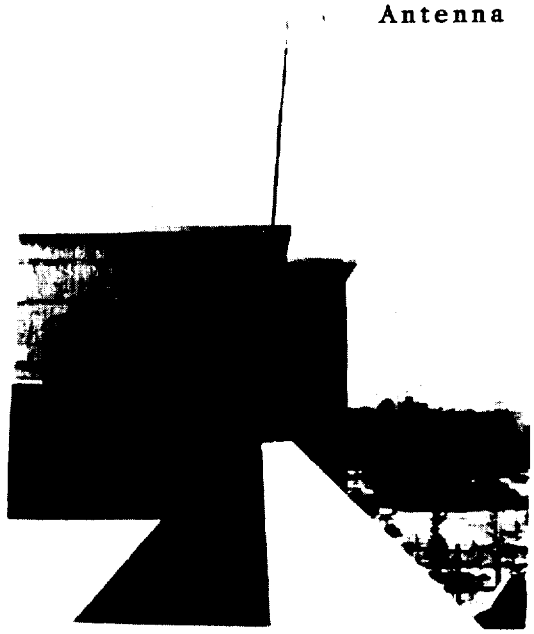
Higashi Mt. from the top of the Medical School
Nagoya University

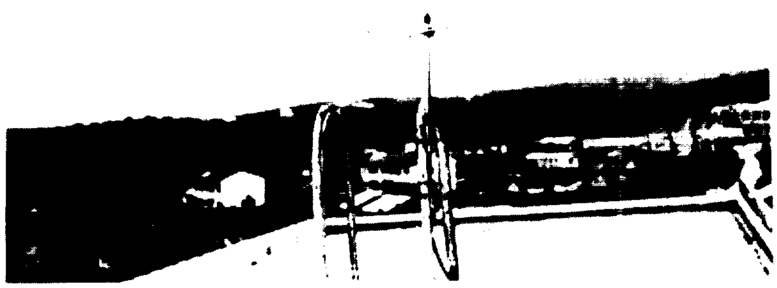
Receiving Side Transmitting Side

Antenna

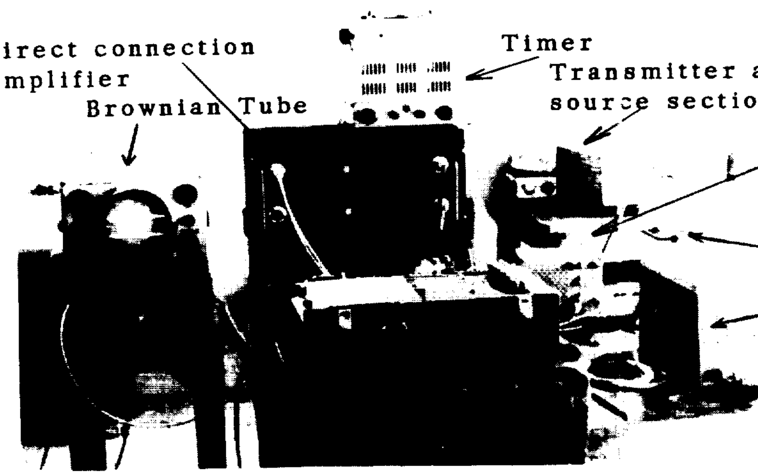


Transmitting Side Antenna

Mt. Higashi (receiving side). The Medical School (transmitting side) viewed from the top of the Engineering School.



Antenna on the receiving side



Part of receiving side apparatus

3 KC Transmitting Mudulator
Low Frequency Vibrator
Brownian Tube
Recording penshirograph. The preamp. of biologic, electrical amplification.
Selector

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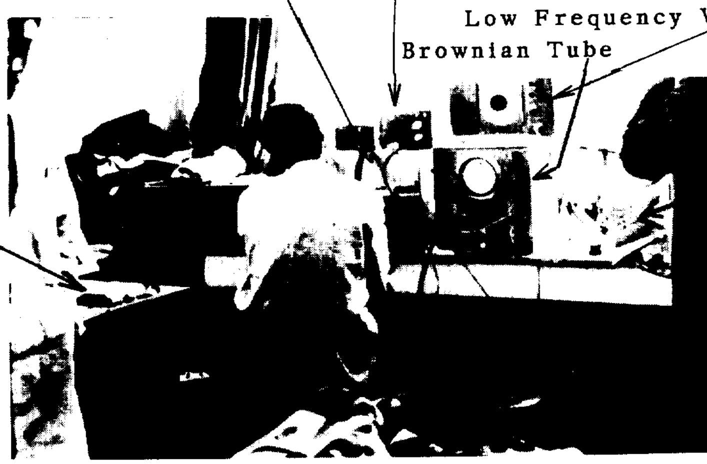
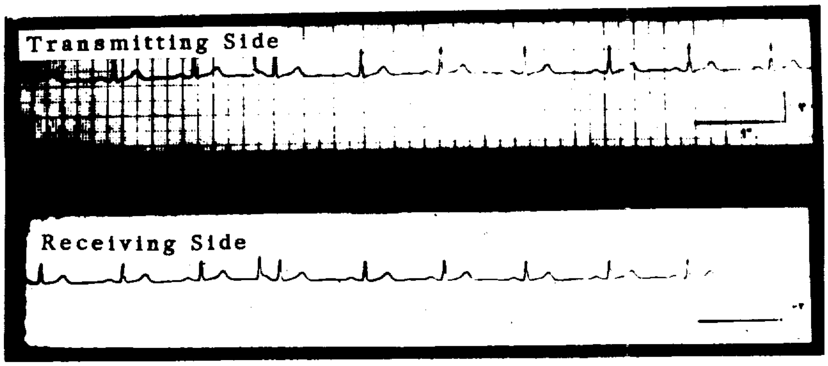
Part of the transmitting side apparatus.

3 KC Transmitting Modulator
Transmitting-receiving Switch Box
Low Frequency Vibrator
Brownian Tube
Radio for making connection.
Recording Penshirograph
150 KC Transmitter
Subject

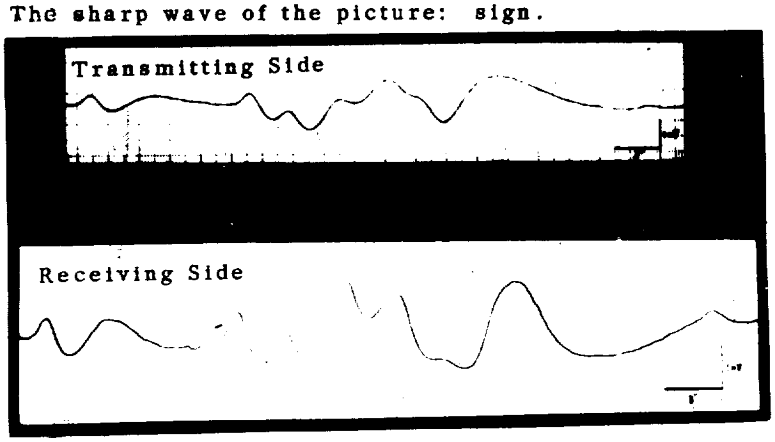


Part of the transmitting apparatus.



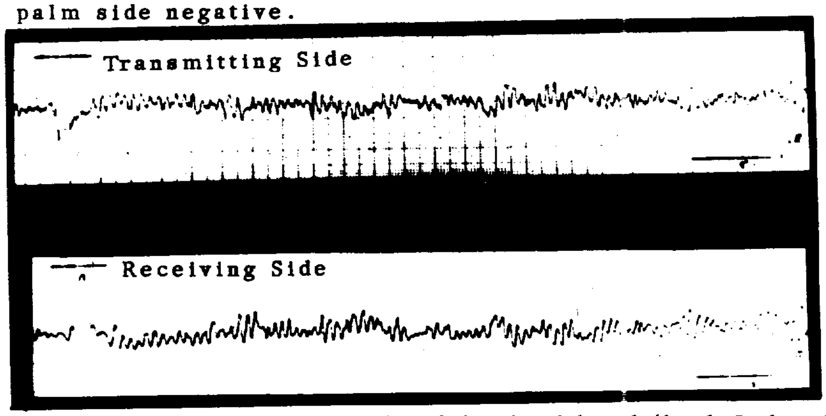
HEART

Electrocardiogram (second Induction). Time const. 1.5 sec. Nov. 11, 1959. The subject: 21 yrs. Lying face-up dormant. The sharp wave of the picture: sign.



SKIN

Electro-current phenomenon of skin. Electric potential induced from thumb. Time const.: 1.5 sec., Nov. 15, 1959. The subject: 27 yrs. Lying face-up, dormant. The up-wave palm side negative.



BRAIN

The brain wave, front of head-back of head (both Induction terminals). Time const. 0.3 sec. Nov. 14, 1959. The subject 21 yrs. Left sign is signal to close eyes. Receiving side's terminal is reversed.